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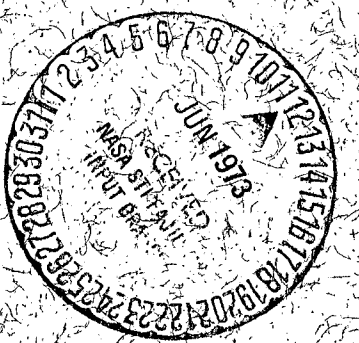

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GAMMA-RAY SPECTROMETER EXPERIMENT, APOLLO 17: NaI(T1) DETECTOR CRYSTAL ACTIVATION

by

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INTRODUCTION

Gamma-ray spectra have been used recently to obtain geochemical analysis of the lunar surface and differential energy spectra of the diffuse gamma-ray background (References 1 and 2). A major source of interference in the gamma-ray spectral measurements may be attributable to the proton-induced activity in the scintillation detectors. The source of these protons during space flight are the primary cosmic rays and in addition, the trapped proton flux when in near Earth orbit. A number of individuals have noticed and discussed this problem (References 3, 4, 5). The Apollo 15 and 16 detectors mounted in the Service Module could have been used for a study of the induced activity but were unfortunately consumed on reentry and therefore, not available for study.

In an attempt to obtain experimental data on the extent of the proton-induced activity, a NaI(Tl) crystal was flown aboard Apollo 17. The crystal was stowed in the Command Module. No measurements were made during flight. After splashdown, the crystal was returned to the aircraft carrier, Ticondorga, where measurements of the induced activity were carried out for a thirty hour period. The crystal was then returned to Oak Ridge National Laboratory (ORNL) where the measurements were continued in a low level counting facility.

EXPERIMENT PROCEDURE

A NaI(Tl) crystal assembly physically identical to that flown aboard Apollo 15 and 16 was used in this experiment (Reference 6). The assembly aboard the Apollo 17 CSM did not include the photo-multiplier, the proton anti-coincidence mantle, and the thermal shield. The detector was a 7 cm x 7 cm right cylindrical crystal. A glass plate was optically sealed to the crystal. MgO was used as the optical reflector inside the crystal assembly. This type of assembly permitted the crystal to be hermetically sealed, and allowed for a simple procedure for optically coupling the crystal assembly to a photomultiplier tube after flight. The crystal and reflector were enclosed in a steel jacket. An identical second crystal assembly which was not flown was used as a control throughout the measurement program. After splashdown, the flight (i.e., activated) crystal was returned to the recovery ship and optically mounted on a photo-multiplier tube and pulse height spectra were obtained. The activated crystal was counted in a large steel low level shield. The crystal counting started about one and a half hours after the Command Module re-entered the earth's atmosphere. Before

splashdown the control or unactivated crystal was optically sealed to a photomultiplier tube and the background was determined in the steel shield. The same photomultiplier tube was used to count the activated and control crystal assemblies. After thirty hours of counting aboard the recovery ship, the detector was flown back to the Oak Ridge National Laboratory (ORNL) where measurements were continued. This permitted the observation of the decay of the longer-lived induced activities. Direct measurements of the induced activities were made by again, optically sealing a photo-multiplier tube to the activated crystal. Indirect measurements using both Ge(Li) detectors and a large scintillation 4π detector in a low level counting system at ORNL (Reference 7) were performed in order to determine the spectral distribution and intensity of the emitted radiations. The 4π scintillation counter is divided into two halves. Both halves can be operated so as to require that there be coincidence events in both halves before an event is analyzed and recorded (coincidence spectra) or both halves can be operated without the coincidence requirement and events independent of their coincidence can be analyzed and recorded (singles spectra).

PRELIMINARY RESULTS

To date it has been possible to obtain qualitative identification of the following nuclear species: ^{24}Na, ^{123}I, ^{124}I, ^{125}I, ^{126}I, ^{128}I, and possibly ^{22}Na, and ^{127}Xe. After suitable calibrations, quantitative concentrations of these radionuclides will be obtained. The results indicate that the induced activity observed after recovery can be attributed mainly to species with half lives of about half a day and longer. Decay products with shorter half lives do not make a large contribution to the post recovery integral count rate. This is not to imply that there are no short half life components. In fact, there seems to be a line at about 0.44 MeV which may be characteristic of ^{128}I. There are a few more regions with relatively short half lives (in order of tens of minutes) which have not as yet been identified.

Figure 1 shows the pulse height spectrum obtained during the first hour and a half of counting after recovery. The spectrum has been corrected for background by subtracting the measurements obtained with the control crystal.

Measurements of the flight and control crystal carried out at the low level counting laboratory at the Oak Ridge National Laboratory prior to flight, indicated the K and Th content of the flight crystal to be slightly higher than that for the control crystal. Thus, one would expect some indication of these elements after background subtraction. This can be seen in the ^{40}K and Th identification in Figure 1. The energy identification for ^{124}I, ^{126}I, and ^{24}Na, indicated in Figure 1 have been verified by measurements made with the Ge(Li) detector and in the low level counting system. Both energy and half life information have been used

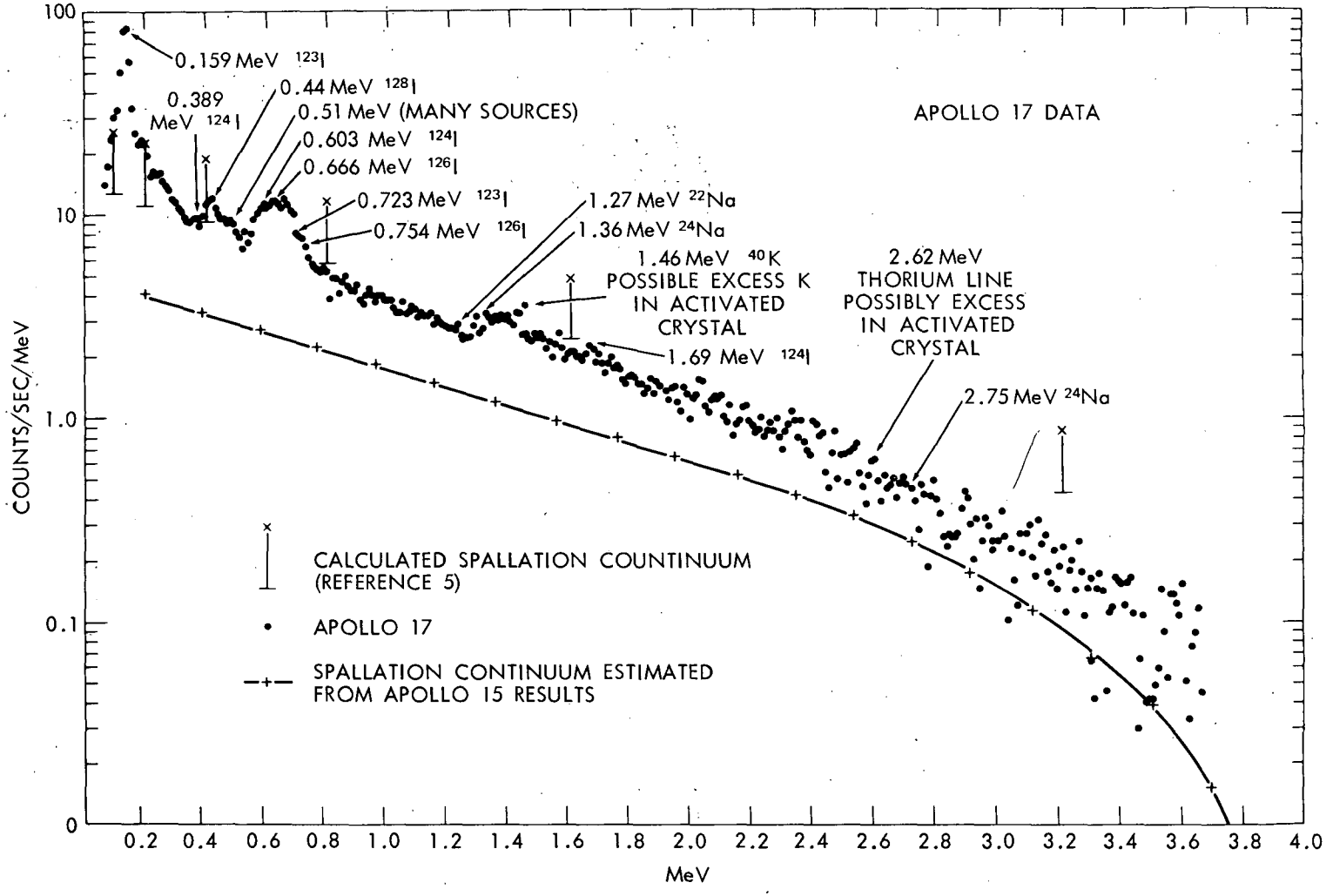

Figure 1. Proton induced activity in 7 cm x 7 cm NaI(Tl) crystal 1-1/2 hours after re-entry. The background has been subtracted. Counting time was 1800 seconds. The spectrum measurement started an hour and a half after re-entry. The spectrum was obtained by direct internal counting of the activated crystal.

to determine the presence of these nuclear species. The ^{123}I and ^{128}I were identified by use of the spectra obtained on board the carrier from both energy and half life determinations. ^{22}Na has been tentatively identified based on a preliminary analysis of the data obtained by the coincidence measurements in the low level counting facility. ^{127}Xe presence has been determined by the identification of energy lines at 0.172 MeV, 0.203 MeV and 0.375 MeV using the Ge (Li) detector. The work will continue in order to obtain quantitative results and possibly identify more nuclear species that have not been obvious from these early analyses.

Figure 2 is a pulse height spectrum obtained using the activated crystal mounted on a photo-multiplier and counted in a lead shield at the Oak Ridge National Laboratory. The counting took place a month and a half after splashdown and the counting time was 60,000 sec. The background count is also shown. The gain of the spectrometer was adjusted to look at the very low energy portion of the γ-ray pulse height spectrum. The characteristic decay spectrum of ^{125}I spectrum can be easily seen.

DISCUSSION

The proton induced crystal activation is of considerable consequence in the analysis of the Apollo 15 and 16 gamma-ray spectra obtained during trans-earth coast. In determining the magnitude and differential energy spectrum of the so-called diffuse gamma-ray spectrum in the 0.3 MeV to 30 MeV region, one of the major sources of interference can be attributed to the crystal activation. Thus, in order to make proper background corrections, both the magnitude and spectral distribution of the cosmic ray induced activity had to be determined. Some theoretical and experimental work had been done to predict the magnitude of this effect (References 4 and 5), but the work on the Apollo 15 diffuse γ-ray measurements (Reference 2) indicated that these predictions were too high. In order to better determine the extent of this effect, the Apollo 17 experiment was performed.

One factor requiring consideration was the difference in the environment during the Apollo 15 and 16 missions compared with Apollo 17 mission. Firstly, the crystals aboard Apollo 15 and 16 were stowed in the Service Module and extended twenty-five feet away from the vehicle for short periods of time, whereas the Apollo 17 crystal was stowed in the Command Module for the total flight time. Thus, there was a difference in mass around the crystal which might cause a difference in the secondary proton and neutron flux in the region of the stowed crystals. Secondly, the exposure profile of the primary flux both in time and spectral distribution were different. The Apollo 17 crystal passed through the near earth trapped proton flux twice before measurement, while the Apollo 15 and 16 detectors had passed through the trapped belts only once before measurement. The Apollo 15 measurement of diffuse gamma-ray spectrum was made

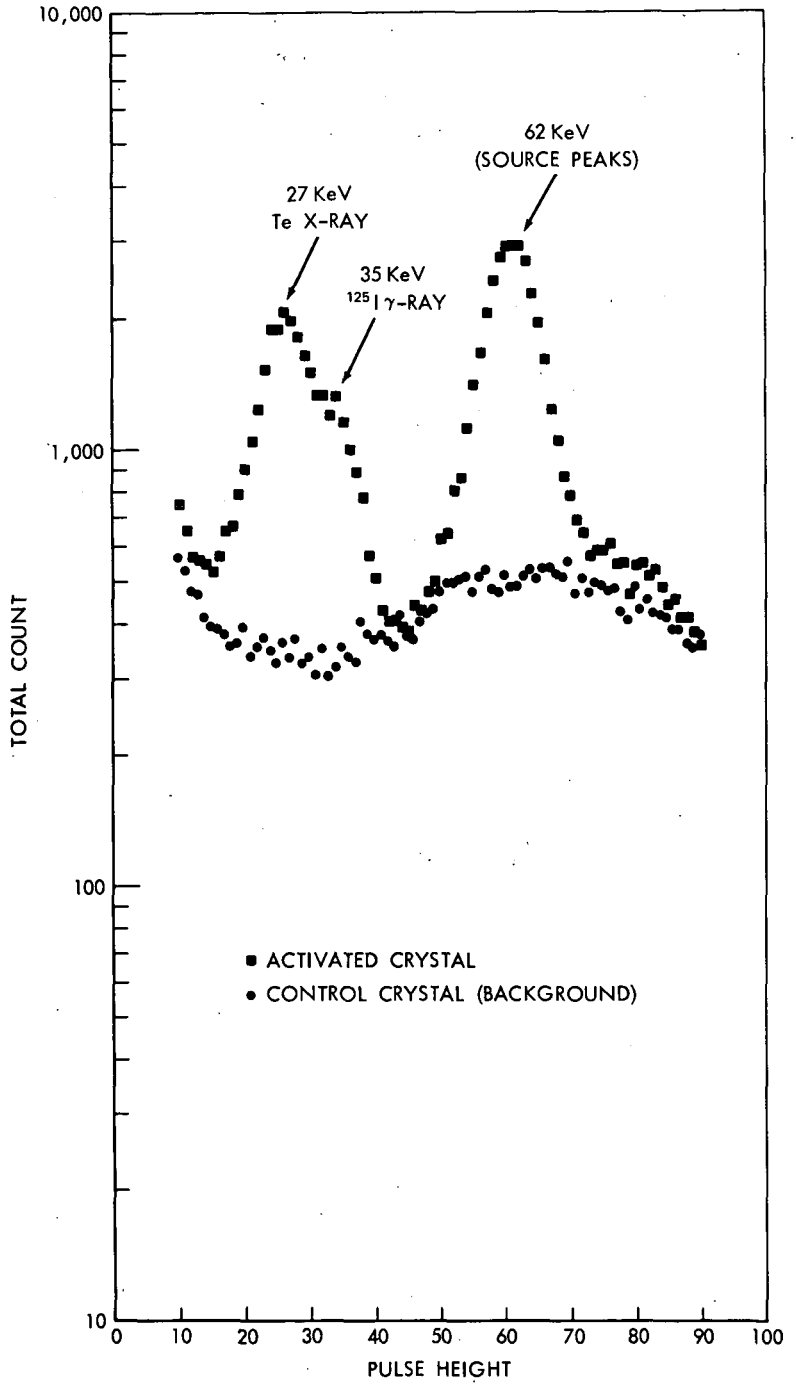

Figure 2. Low energy spectrum of the proton induced activity in a 7 cm x 7 cm NaI(Tl) crystal. Measured a month and a half after splashdown. The background obtained with a similar control crystal is also shown. Counting time was 60,000 seconds. The spectrum was obtained by direct internal counting of the activated crystal.

about 250 hours after lift off while the Apollo 17 measurements were made some 305 hours after lift off. It has not as yet been determined how significant these differences are in terms of trying to infer the magnitude of the proton-induced activity in the Apollo 15 and 16 detectors from the Apollo 17 measurements.

The shape of the proton-induced gamma-ray pulse height spectrum can be divided into two parts, the discrete line spectrum and the continuous spectrum. The discrete line pulse height spectrum for activated nuclear species in the crystal is produced by monoenergetic gamma-rays emitted after electron capture. The continuum for such nuclear species is produced by electrons, positrons, positron annihilation, and gamma rays (other than those emitted after electron capture) interacting in the crystal. If the material surrounding the crystal is radioactive (eg some ^{24}Na, Th, ^{40}K) then monoenergetic gamma rays independent of the mode of decay can be seen in the crystal as a discrete line pulse height spectrum. In Figure 1, the discrete lines are indicated and the continuous distribution can be seen underneath.

In the Apollo 15 trans-earth spectrum (Reference 2), the ^{124}I 0.606 MeV, and the ^{126}I 0.66 MeV lines can be identified. It has been calculated that the integrated count rate in this region above the continuum for Apollo 15 is half of that observed in the same region above the continuum for the Apollo 17 mission. This difference cannot be attributed to the difference in exposure time alone. Thus, the difference in local mass and the passage through the near earth trapped radiation belts a second time may be the cause of this increase.

In Figure 1 the magnitude of the continuum and associated error as predicted in Reference 5 is compared with the Apollo 17 measurement taken aboard the recovery ship. The magnitude of the continuum inferred from the Apollo 15 data (Reference 2) is also shown. Its magnitude is consistent with Apollo 17 results if it is considered that the discrete line magnitude for ^{124}I and ^{126}I is down by a factor of two. This also assumes that the shorter half lived nuclides and the prompt gamma-ray emission is small compared to the longer half lived emitters.

From the preliminary results it seems that the dominant reaction are of the (p, pxn) type. Neutron interactions do not seem to play an important part in producing the induced radiation seen during the post-flight recovery measurements.

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